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Radar Back-Scattering Measurements
from "Moon-Like" Surfaces

by

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REPORT 1388-9

REPORT

by

THE OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS 12, OHIO

Cooperator	National Aeronautics and Space Administration 1520 H Street, N. W. Washington 25, D. C.
Grant Number	NsG-213-61
Investigation of	Theoretical and Experimental Analysis of the Electromagnetic Scattering and Radiative Properties of Terrain, with Emphasis on Lunar-Like Surfaces
Subject of Report	Radar Back-Scattering Measurements from "Moon-Like" Surfaces
Submitted by	W. H. Peake and R. C. Taylor Antenna Laboratory Department of Electrical Engineering
Date	1 May 1963

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RADAR BACK-SCATTERING MEASUREMENTS FROM "MOON-LIKE" SURFACES

I. INTRODUCTION

The problem of relating the surface structure of the moon to its radar scattering behavior is becoming of increasing practical importance as the moment for the first manned "soft-landing" approaches. For example, to avoid the weight penalties of overdesign, the designer of lunar approach radars must have complete information of the scattering properties of the lunar surface. Similarly, the choice of a suitable landing spot will be influenced by local surface roughness. Such roughness conditions can often be most easily investigated at wavelengths of the same order as the surface structure. Thus roughness scales of the order of a few feet to a few inches, which are the significant scales for landing operations, can be studied at the lower microwave frequencies.

In the last few years a number of earth-moon radar experiments have been performed, and have provided much data on the mean-square slope of the relatively large-scale structure of the moon. There is much less information on the small-scale structure which is revealed by the "diffuse" part of the lunar scattering diagram, and which so far has been measured at only two wavelengths (68 cm and 3.6 cm). These two measurements[1] have not yet been adequately interpreted in terms of surface roughness because of the absence of similar scattering data on comparable terrestrial surfaces. In this paper, some of these basic data are provided for a number of rough terrestrial surfaces (gravel and rubble), and are compared with the lunar scattering data.

II. DESCRIPTION OF PARAMETER

The basic radar back-scattering experiment makes use of a high-gain antenna to illuminate a section of terrain at range R shown in Figure 1. The average received pulse power P_r is given by the well-known radar equation

$$P_r = \frac{\sigma G^2 \, P_O \lambda^2 \cdot f(\theta, \phi)^4}{(4\pi)^3 \, R4}$$

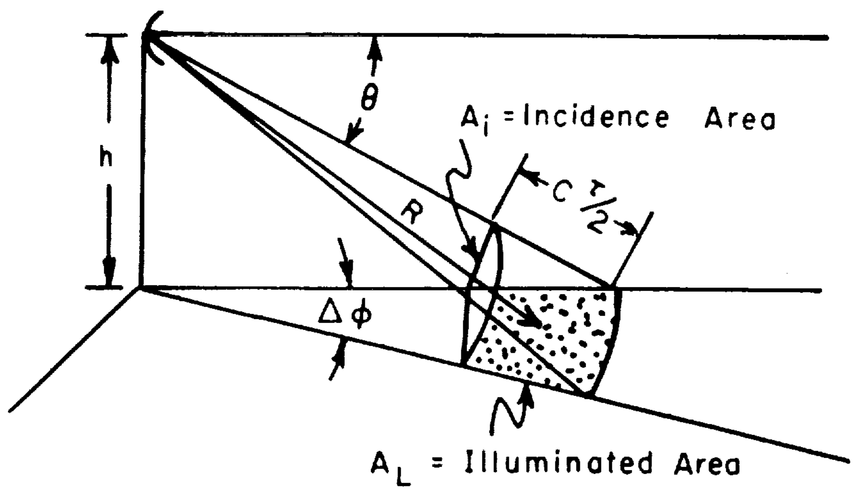

Fig. 1. Geometry for terrain scattering.

θ = depression angle
λ = wavelength
$f(\theta,\phi)$ = antenna voltage pattern
P_o = transmitted power
G = maximum antenna gain
σ = radar cross-section

The parameter σ is the average radar cross section of the terrain and, at least for the random homogeneous terrain considered here it is proportional to the area of the terrain contributing to the return at any instant.

In order to eliminate effects of pulse width, geometry etc., on the measured return, and to work with a parameter which is characteristic only of the terrain, it is convenient to introduce a parameter γ, defined through the equation $\sigma = \gamma A_i$. A_i is the incidence area, the area perpendicular to the line of sight through which passes all of the energy contributing to the return at a given range and time. For the usual case of pulsed radars,

$$A_i = \left(\frac{c\,\tau}{2}\right)\tan\,\theta R \Delta\,\phi$$

τ = effective pulse width
$\Delta\phi$ = effective azimuth beam width
θ = incidence angle
c = velocity of light

When γ and A_i are substituted into the radar equation, it takes the form

$$P_r = [\gamma][\tan\theta |f(\theta,\phi)|^4][P_o \lambda^2 \Delta\phi \frac{c\tau}{2} G^2]$$

terrain geometry and system

It can be seen that the influence of the terrain is isolated in the single factor γ.

The parameter σ_o (the back-scattering cross-section per unit area of surface) often found in the literature, is related to γ by the expression $\sigma_o = \gamma \sin\theta$.

III. EXPERIMENTAL MEASUREMENTS

The results of the radar back-scattering measurements of rubble-like surfaces are shown in Figures 2 through 7. Here the radar back-scattering parameter γ is plotted as a function of the grazing angle θ. The values of γ shown in Figures 2 through 7 are average values determined by averaging the return from many samples of terrain. It is evident from the results of the measurements shown in Figures 2, 3, and 4 that the magnitude of the back-scattering is dependent upon both incidence angle and surface roughness for quasi-smooth surfaces. However, this dependence upon incidence angle and surface roughness disappears as the surface becomes rough in terms of wavelength, as shown in Figure 4. One interesting feature shown in Figure 4 is the inversion of the magnitude of the back-scattering as a function of frequency. For the case of stone the largest return was obtained at X-band, while the largest return from gravel and sand was at K_A-band. This effect could be accounted for by a resonance phenomenon since the particle size at X-band is about a wavelength, or by a change in the complex dielectric constant. For a very rough surface with a semi-infinite thickness and no changes in the over-all slope of the surface, the magnitude of the back-scattering is primarily dependent upon the complex dielectric constant of the material.[2]

It can be seen from the results of the measurements shown in Figures 5, 6, and 7 that a definite polarization dependence exists for

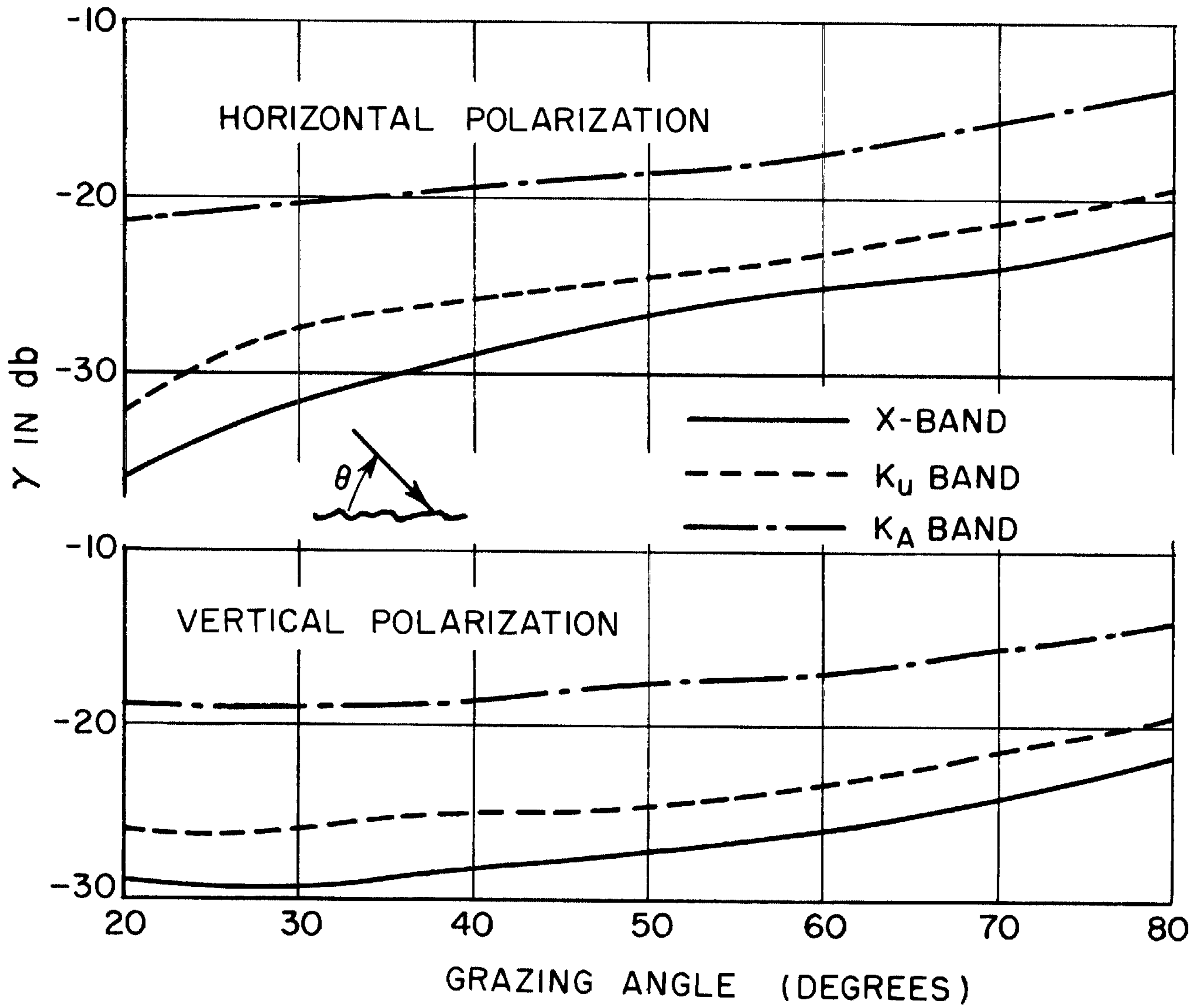

Fig. 2. Frequency dependence of radar backscattering for a smooth surface (sand).

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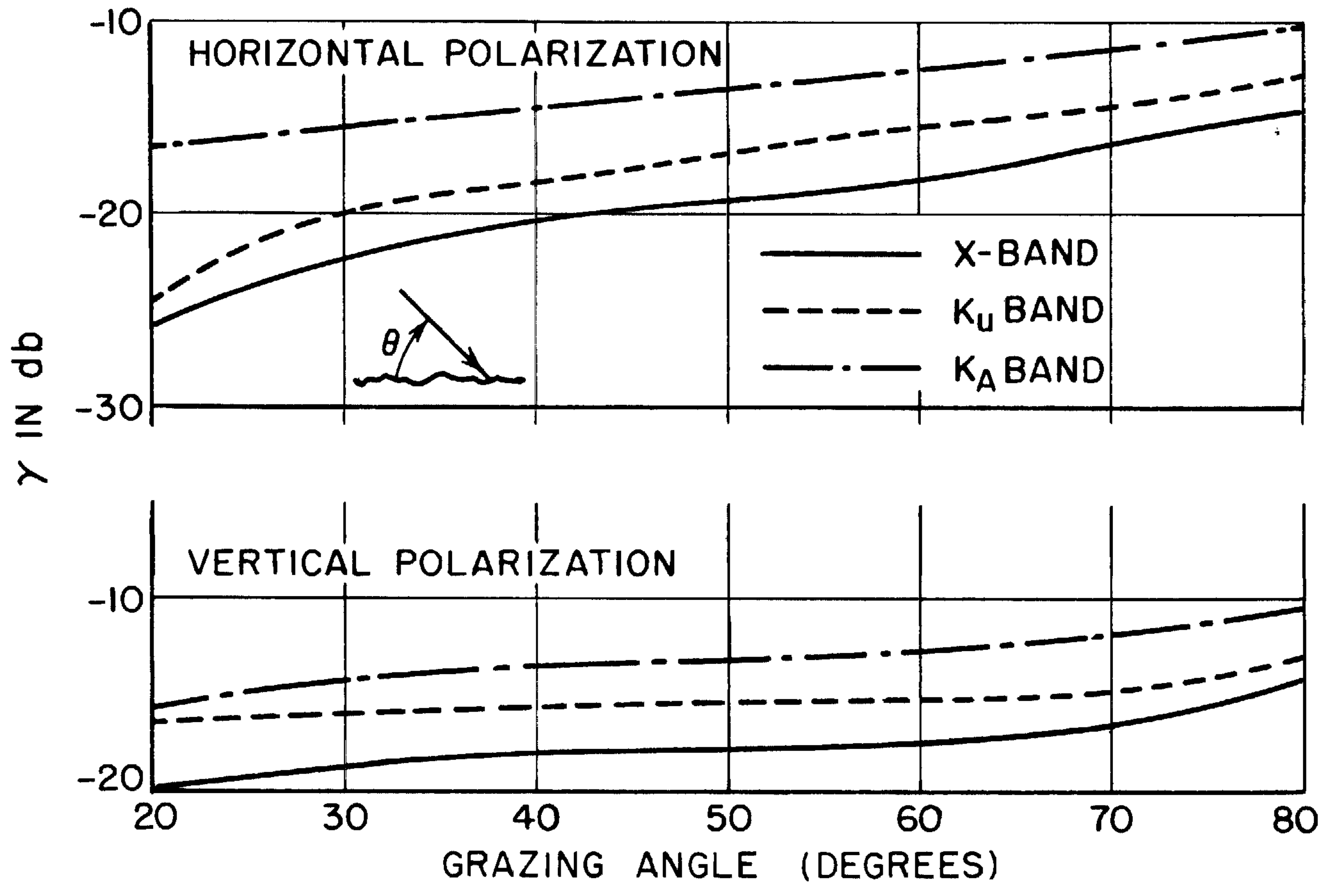

Fig. 3. Frequency dependence of radar backscattering for a slightly rough surface (gravel). (Average diameter of rounded gravel particles $\sim$ 1 cm)

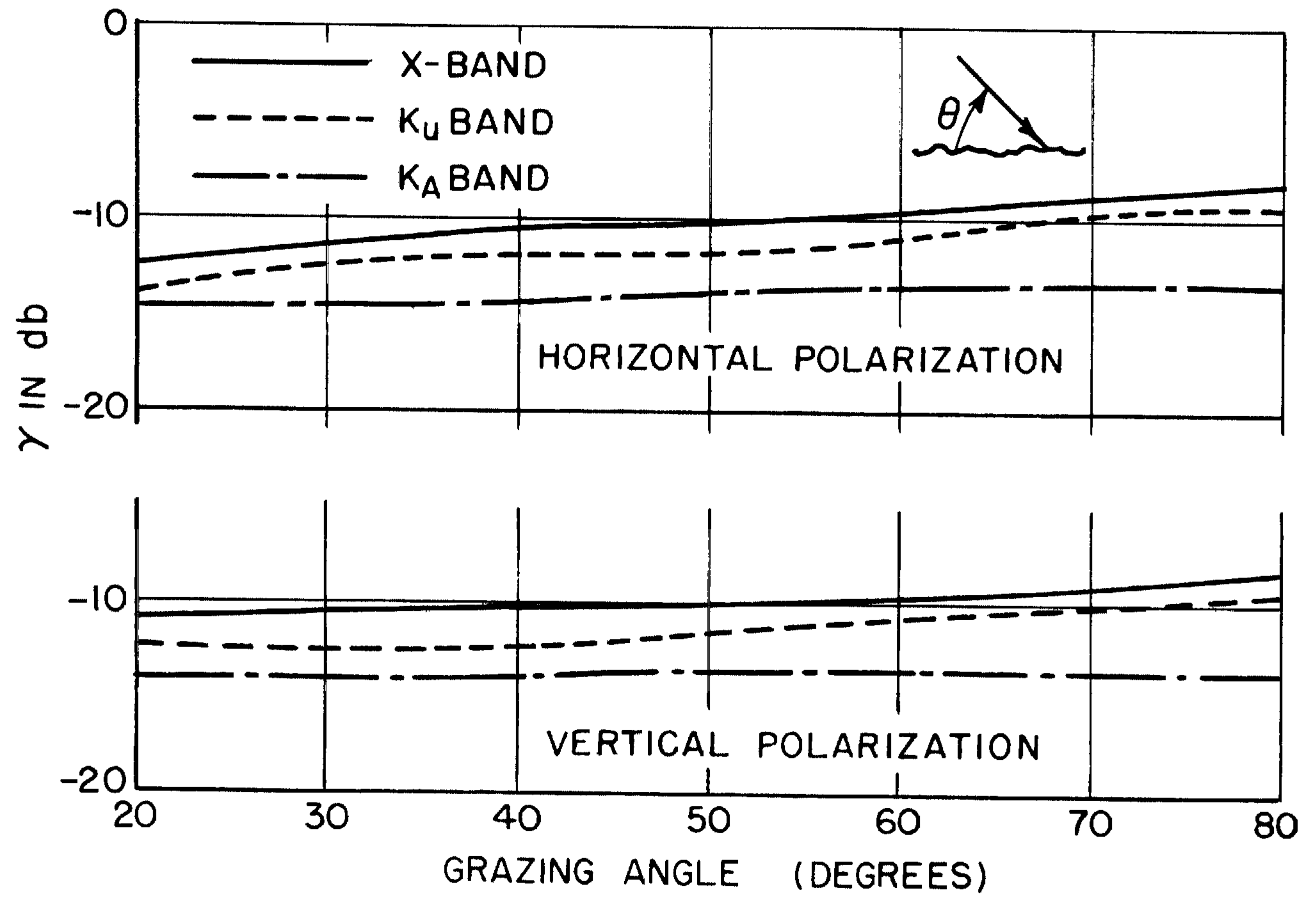

Fig. 4. Frequency dependence of radar backscattering for a rough surface (stone). (Average diameter of crushed stone particles $\sim$ 3 to 5 cm)

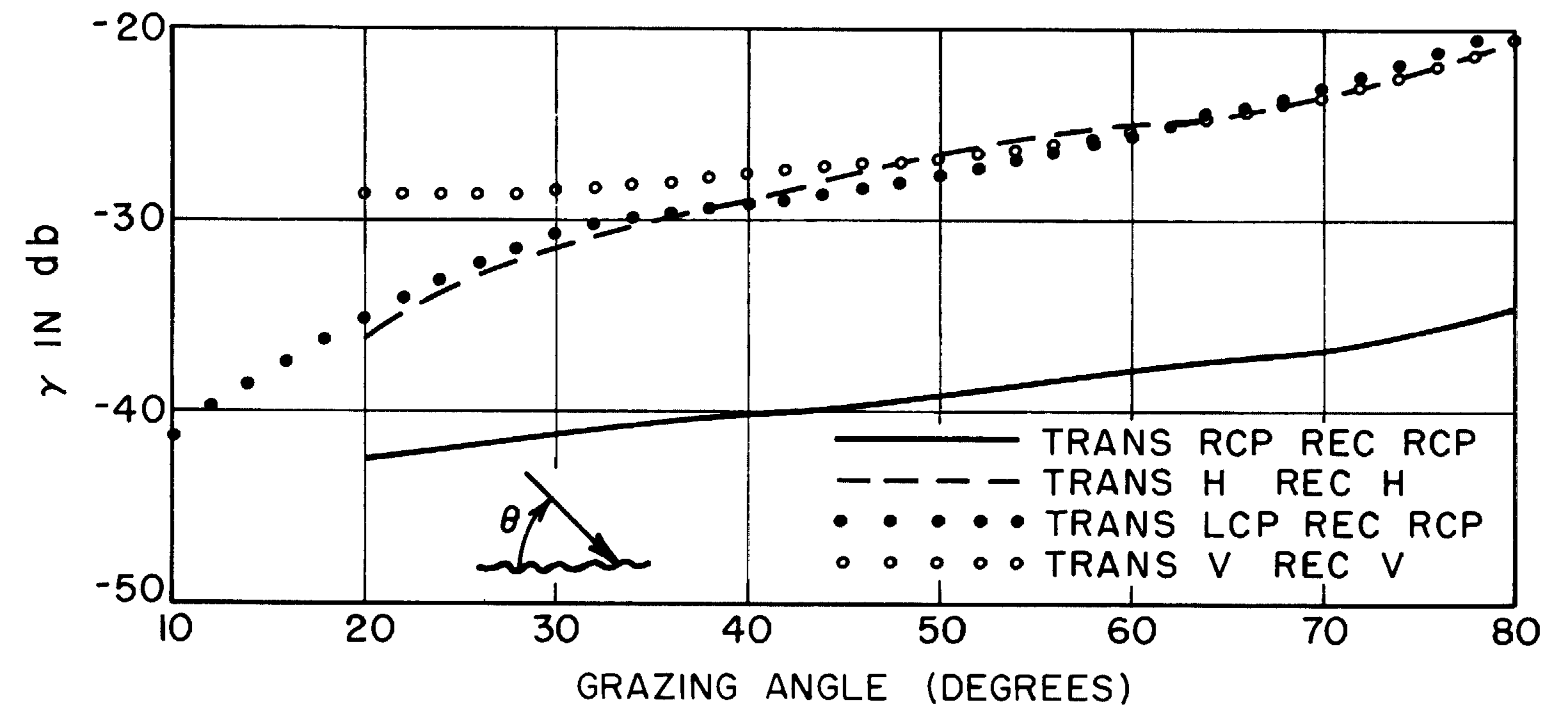

Fig. 5. Polarization dependence of radar backscattering for a smooth surface (sand).

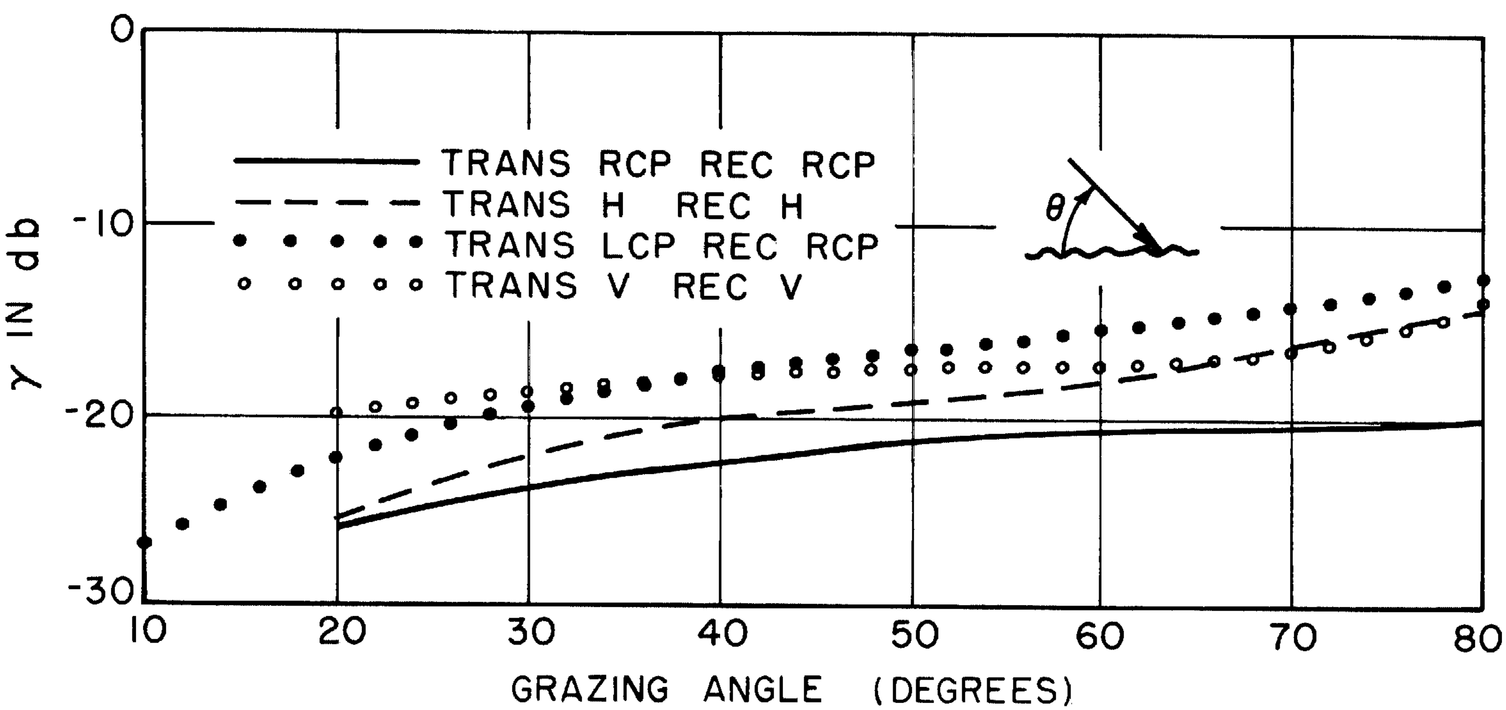

Fig. 6. Polarization dependence of radar backscattering for a slightly rough surface (gravel).

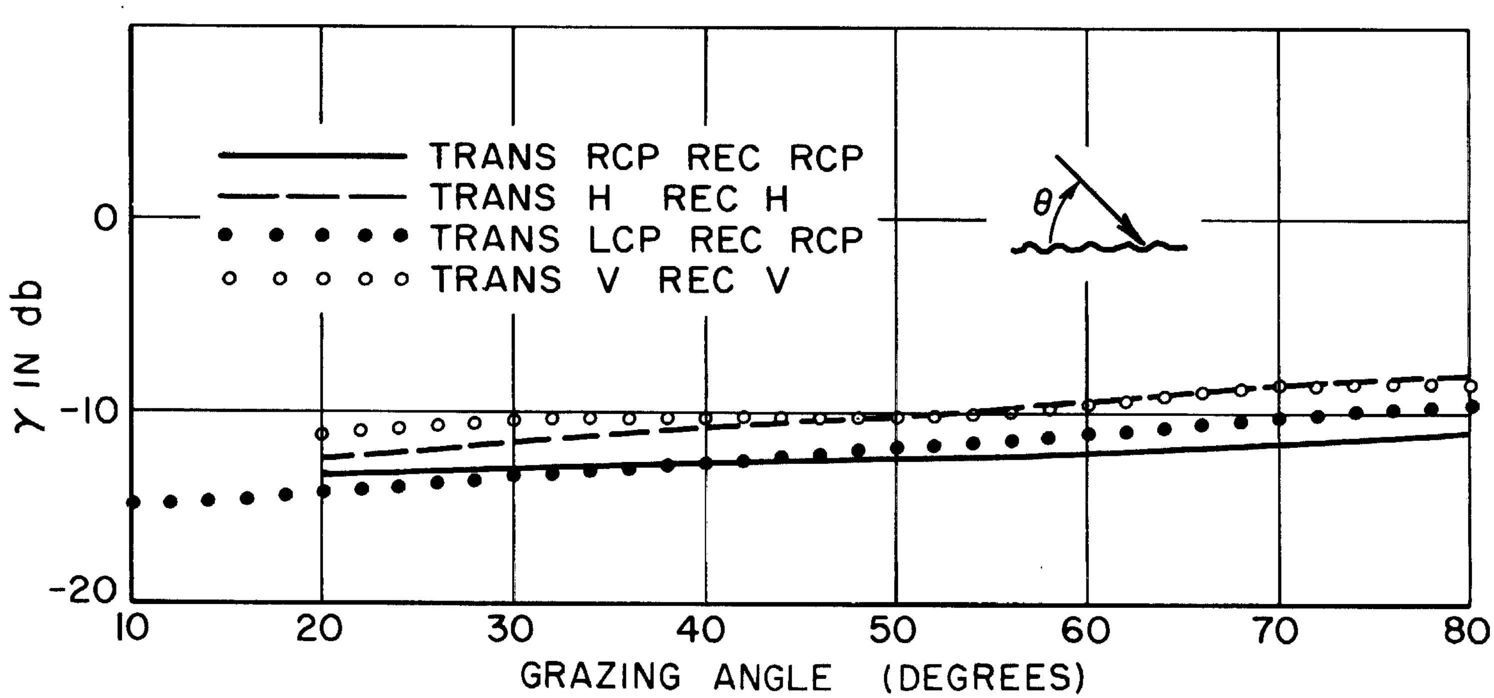

Fig. 7. Polarization dependence of radar backscattering for a rough surface (stone).

the quasi-smooth surface. However, as was the case for the incidence angle and surface roughness dependence, the polarization dependence disappears as the surface becomes rough in terms of wavelength, as shown in Figure 7.

IV. NORMALIZED ROUGHNESS

The quantitative relation between surface roughness and back-scattering can best be illustrated by plotting some of the data of Figures 2-7 in terms of a normalized roughness parameter, $\xi = D \sin\theta/\lambda$ where D is the diameter of the individual stones or particles, λ is the wavelength, and the factor $\sin\theta$ is introduced in analogy with the Rayleigh criterion for effects of roughness on reflection. This has been done in Figure 8, and it is seen that for $\xi < 1/4$, the return falls off roughly as $1/\lambda^2$, whereas for $\xi > 1/4$ the return is a constant, more or less independent of roughness (corresponding to "optical" scattering). The general level of the curve would move up or down for materials of different dielectric constants or reflection coefficients. Thus by measuring the back-scattering from a surface at a number of angles and wavelengths, it should be possible to estimate the roughness by locating the break-point ($\xi = 1/4$) and to estimate the dielectric constant by measuring the optical level.

As an example of the use of this technique, points corresponding to Pettengill's measurement[1] of the diffuse part of the lunar return at 68 cm, indicated by "P", have also been plotted in Figure 8, assuming $D \simeq 15$ cm. A more suggestive comparison between the lunar and terrestial data is given in Figure 9, which plots γ for the rubble surfaces, and also the lunar measurement of Pettengill (68 cm; circular and crossed-circular polarization) and Evans (3.6 cm, "linear" polarization); the curve for 3.6 cm has been raised 6 db above the actual measured value to refer all curves to roughly the same dielectric constant. The two lunar curves seem to correspond fairly well in both wavelength and polarization dependence with the terrestrial materials studies, and are not inconsistent with the previous suggestion of a small-scale roughness of about half a foot for the lunar surface.

V. CONCLUSION

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Measurements of back-scattering from a number of rubble-like surfaces have been made for several polarization states. For such

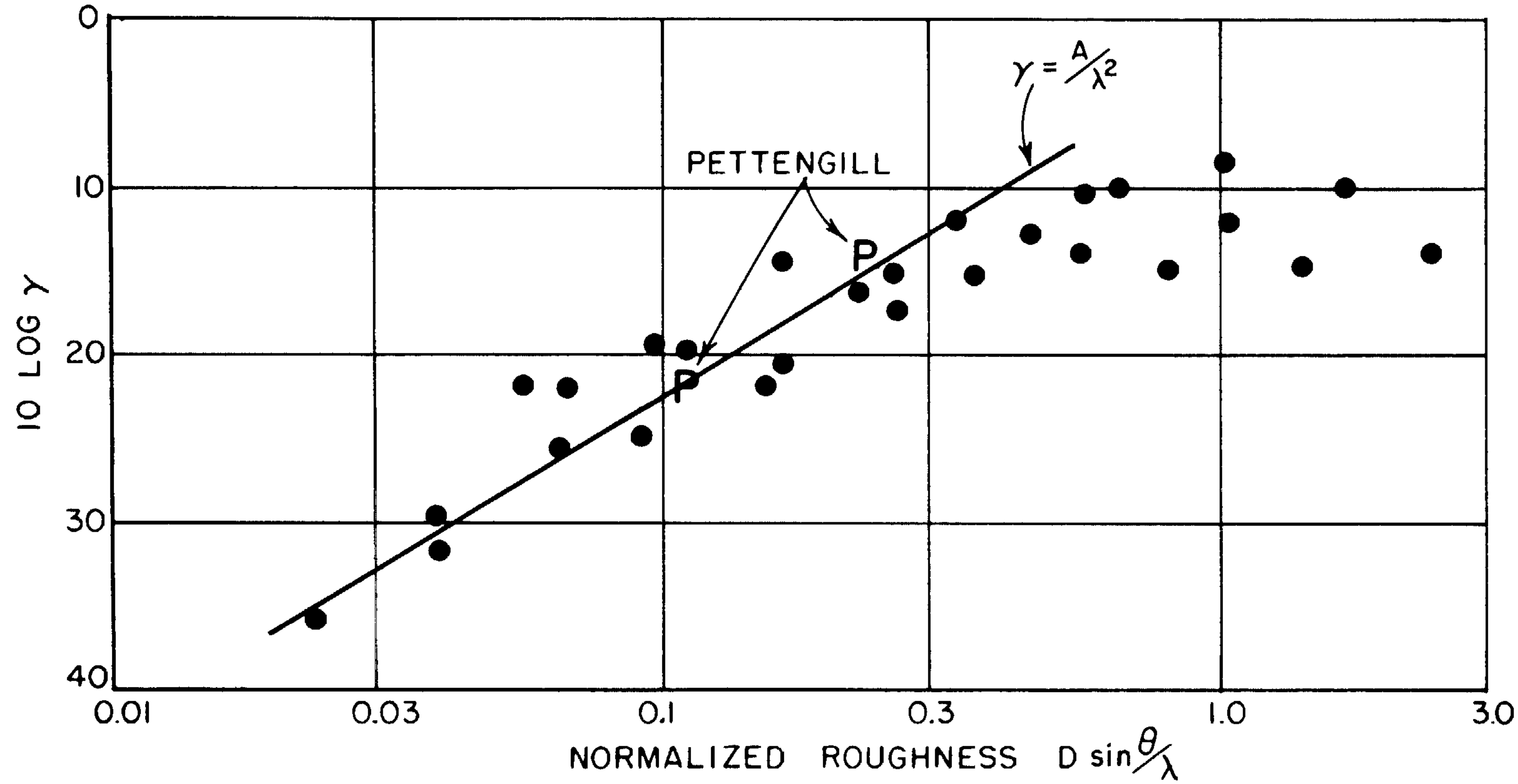

Fig. 8. Radar return vs normalized roughness for stone, gravel and sand surfaces at X, K_u and K_a band.

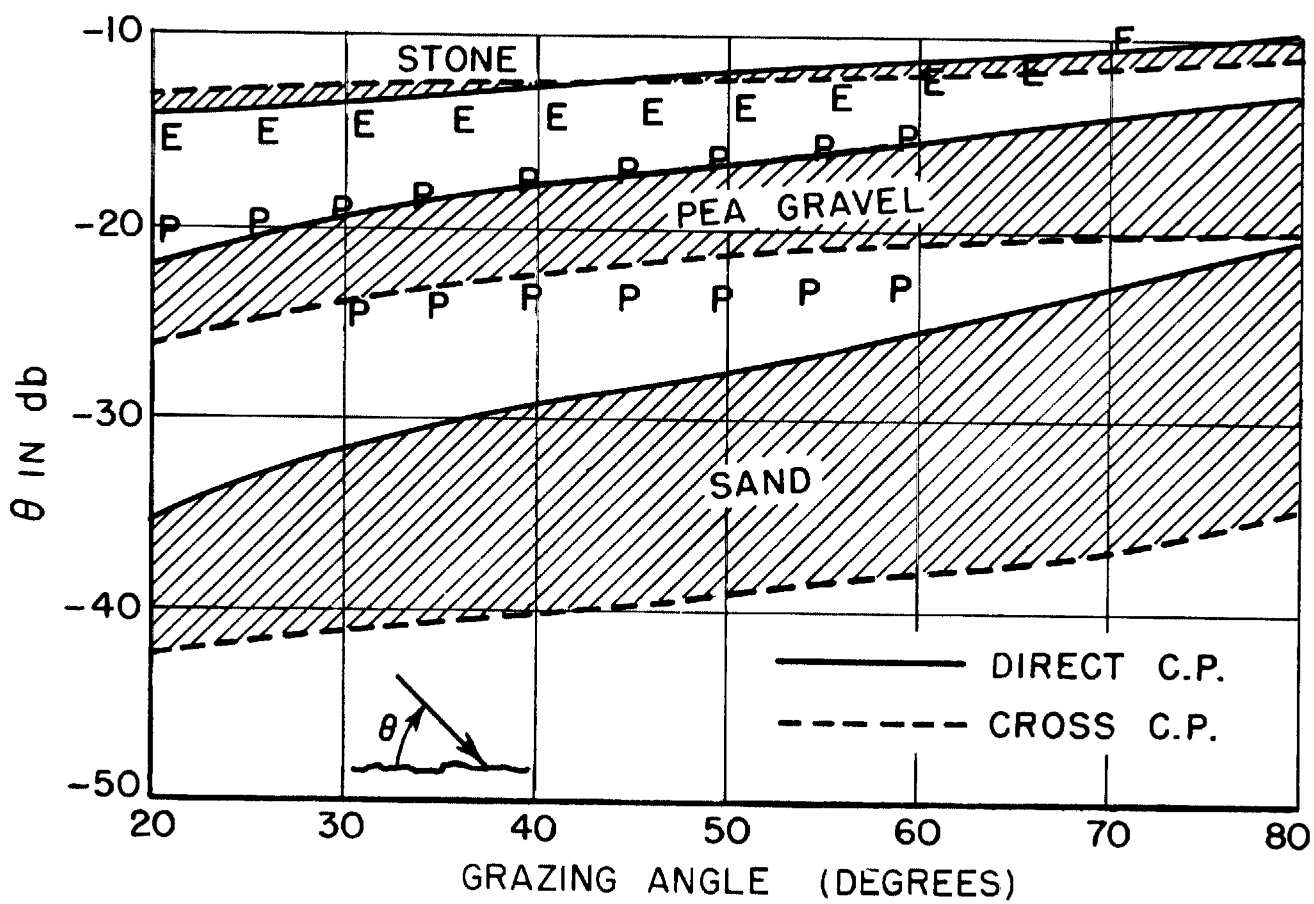

Fig. 9. Direct and cross polarization, radar backscattering as a function of surface roughness.

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surfaces there is a qualitative relation between the surface roughness, and angular and polarization dependence of the back-scatter. This relation may be used to estimate surface roughness, and perhaps dielectric constant, from back-scattering measurements.

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